KNIGHTS FERRY GRAVEL REPLENISHMENT PROJECT

Work Authority #1469-8520, Project #97-N21

FINAL REPORT

Produced for

CALFED Bay Delta Program
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9 February 2002

INTRODUCTION

The goal of the Knights Ferry Gravel Replenishment Project (KFGRP) was to improve the quantity and quality of spawning and incubation habitat for fall-run chinook salmon (*Oncorhynchus tshawytscha)* in lower the Stanislaus River (Figure 1) and to evaluate different methods of restoring spawning habitat. Gravel and gold mining was intensive on the Stanislaus River between the mid 1850s and the 1970s and much of the spawning habitat was excavated from the primary spawning and rearing reaches between Goodwin Dam and Oakdale (Mesick 2001a, CMC 2002b). The few natural spawning sites that were not mined became armored as high flows flushed the gravel from the riffles into the numerous inriver mine pits.

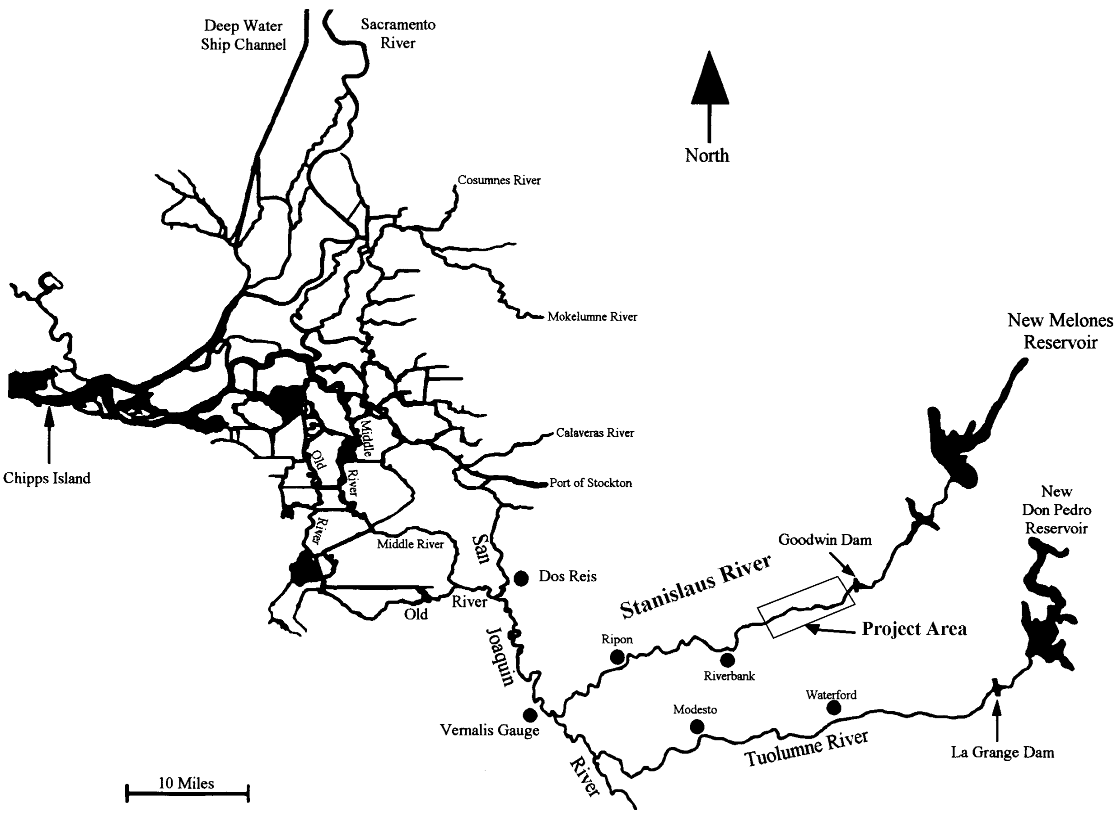

Figure 1. Map of the Sacramento-San Joaquin Delta showing the Stanislaus River, Goodwin Dam, and the project area.

Although gravel augmentation is a logical solution to the problems caused by inriver gravel mining, early restoration projects in the San Joaquin tributaries were poorly used by spawning salmon (Mesick 2001b) and as a result, only a limited number of new projects were being proposed. The early projects on the Stanislaus River imported gravel from the Merced River, used crushed rock, removed all rock less than 1/2-inch in diameter, and created relatively flat spawning beds, but otherwise appeared to provide optimum spawning habitat for salmon. The KFGRP tested hypotheses that the size and source of restoration gravel affects spawner use (CMC 1999a). Another hypothesis tested was that salmon prefer to spawn in areas where gravel is naturally deposited.

Another concern was that salmon clean the gravel during redd construction and there was no evidence to suggest that adding clean gravel to construct spawning habitat would improve egg survival to emergence. The KFGRP tested two hypotheses that creating spawning habitat by adding clean gravel would provide higher intragravel dissolved oxygen concentrations and higher intragravel flows compared to conditions in natural spawning areas.

The fluvial geomorphic performance of the restored sites was also monitored. The rate that gravel was flushed from the sites during high flow releases was evaluated relative to the configuration of the natural streambed and the presence of functional floodplain habitat. It was hypothesized that the gravel would not be flushed away at abnormally high rates at sites where gravel was naturally deposited upstream of hydraulic controls and where the adjacent floodplain was not isolated from the river by dikes.

IMPLEMENTATION

The National Fish and Wildlife Foundation executed the KFGRP contract with Carl Mesick Consultants on 30 September 1998. By 31 March 1999, applications were submitted for all environmental permits and by 15 August 1999, copies of all the permits were submitted to NFWF and CALFED. Construction began on 4 August 1999 and was completed by 24 September 1999. A total of 13,000 tons of gravel was placed at 18 project sites in the Stanislaus River between Goodwin Dam and Oakdale: Six sites received a total of 4,490 tons of Stanislaus River rock 1/4 to 5 inches in diameter; another six sites received a total of 5,570 tons of Stanislaus River rock 3/8 to 5 inches in diameter; and six other sites received a total of 2,940 tons of Tuolumne River rock 3/8 to 5 inches in diameter. The total cost of the project was $667,887. CALFED provided $561,407, the Stockton East Water District provided approximately $90,000, and Carl Mesick Consultants donated approximately $16,480 in labor and expenses.

The KFGRP environmental studies were divided into three tasks:

- Task 3, Pre-Project Habitat Evaluations, which documented baseline conditions at the 18 project sites and 7 control sites in fall 1998 and summer 1999;
- Task 5, Initial Post-Project Habitat Evaluations, which documented spawning and incubation conditions in fall 1999; and
- Task 6, Second Year Post-Project Habitat Evaluations, which documented spawning and incubation conditions in fall 2000.

Dr. Mesick gave two presentations on the results of the KFGRP environmental studies and is scheduled to give a third presentation in March 2002. The first presentation, “Spawning habitat restoration in the Stanislaus River” was presented at the CALFED Science Conference 2000 in Sacramento on 3 October 2000. The second, “Egg incubation conditions in restored riffles in the Stanislaus River”, was presented at the American Fisheries Society Annual Meeting in Santa Rosa on 31 March 2001. The third presentation, “The Knights Ferry Gravel Replenishment Project, Stanislaus River, will be presented at the Salmonid Restoration Federation’s 20th Annual Conference in Ukiah, California on 3 March 2002.

RESULTS AND CONCLUSIONS

The results of the post-project studies suggest that adding clean gravel to the Stanislaus River benefitted fall-run chinook salmon by increasing the amount of spawning habitat and thereby reducing the number of salmon eggs killed and alevins entombed by redd superimposition. Redd superimposition was commonly observed in the primary spawning reach in the Stanislaus River between Goodwin Dam and Willms pond during fall 2000 (CMC 2002b) and in previous studies (Mesick 2001b; CMC 2002a). It is likely that the gravel and gold mining that occurred in the active channel of the Stanislaus Gravel between the 1930s and 1970s substantially reduced the availability of spawning habitat and thereby caused high rates of redd superimposition by crowding the spawners (Mesick 2001a). Between 1949 and 1999, which is after the peak mining period during the early 1940s, Kondolf et al. (2001) estimated that 1,031,800 yd^3 of gravel were extracted from the active channel between Goodwin Dam (RM 58.5) and Oakdale (RM 40). The Knights Ferry Gravel Replenishment Project added a total of 13,000 tons of gravel to the streambed and so only a small fraction of the historical spawning habitat in the Stanislaus River has been restored.

The KFGRP studies also provided valuable information regarding the restoration of spawning habitat for chinook salmon. The Task 5 Fall 1999 studies demonstrated that fall-run chinook salmon will spawn immediately at the tails of pools constructed with newly placed gravel (CMC 2002a). The density of redds at the study riffles was significantly correlated with the distance downstream from Goodwin Dam during all three years of study and so statistical comparisons of redd densities between project sites and control sites were based on the regressions with distance downstream. Presumably adult salmon migrate upstream until they encounter a cue in the surface flow, such as suitable levels of dissolved oxygen or water temperature. Regardless of the cue used by the salmon to select a spawning site, their behavior results in relatively high redd densities at the upstream riffles and low redd densities at the downstream riffles. Therefore, to maximize the benefits of restoration, future restoration sites should be selected in the upstream areas where densities of spawners are high. In the Stanislaus River, most chinook salmon spawned in the seven-mile-long reach between Goodwin Dam and Willms Pond (Riffle R20).

Redd densities were significantly higher in gravel obtained from the Stanislaus River's floodplain compared to similarly-sized gravel imported from the Tuolumne River's floodplain during both fall 1999 and fall 2000 (Figure 2). Initially in fall 1999, the redd densities were higher, although not significantly, in Stanislaus River gravel cleaned with a 1/4-inch screen than in the gravel cleaned with a 3/8-inch screen, whereas the redd densities were nearly identical between these two groups of riffles in fall 2000. The relative density of redds also increased at the sites with Tuolumne River rock in fall 2000 suggesting that the restoration gravel rapidly "seasoned".

Chinook salmon probably select spawning sites based on the mineral content or odor of the gravel and the ease of digging a redd and "seasoning" and fine sediment intrusion affect the suitability of restoration gravel over time. Although the mineral content of the different sources of gravel was not determined, the Stanislaus gravel and Tuolumne gravel differed in color and presumably mineral content and it is likely that the salmon could smell these differences. One possible explanation for seasoning is that as the minerals dissolve from the gravel's surface, the intensity of the odor of the foreign rock diminishes over time. In addition, salmon frequently construct redds at artificial redd sites, where the construction of the artificial redd in the

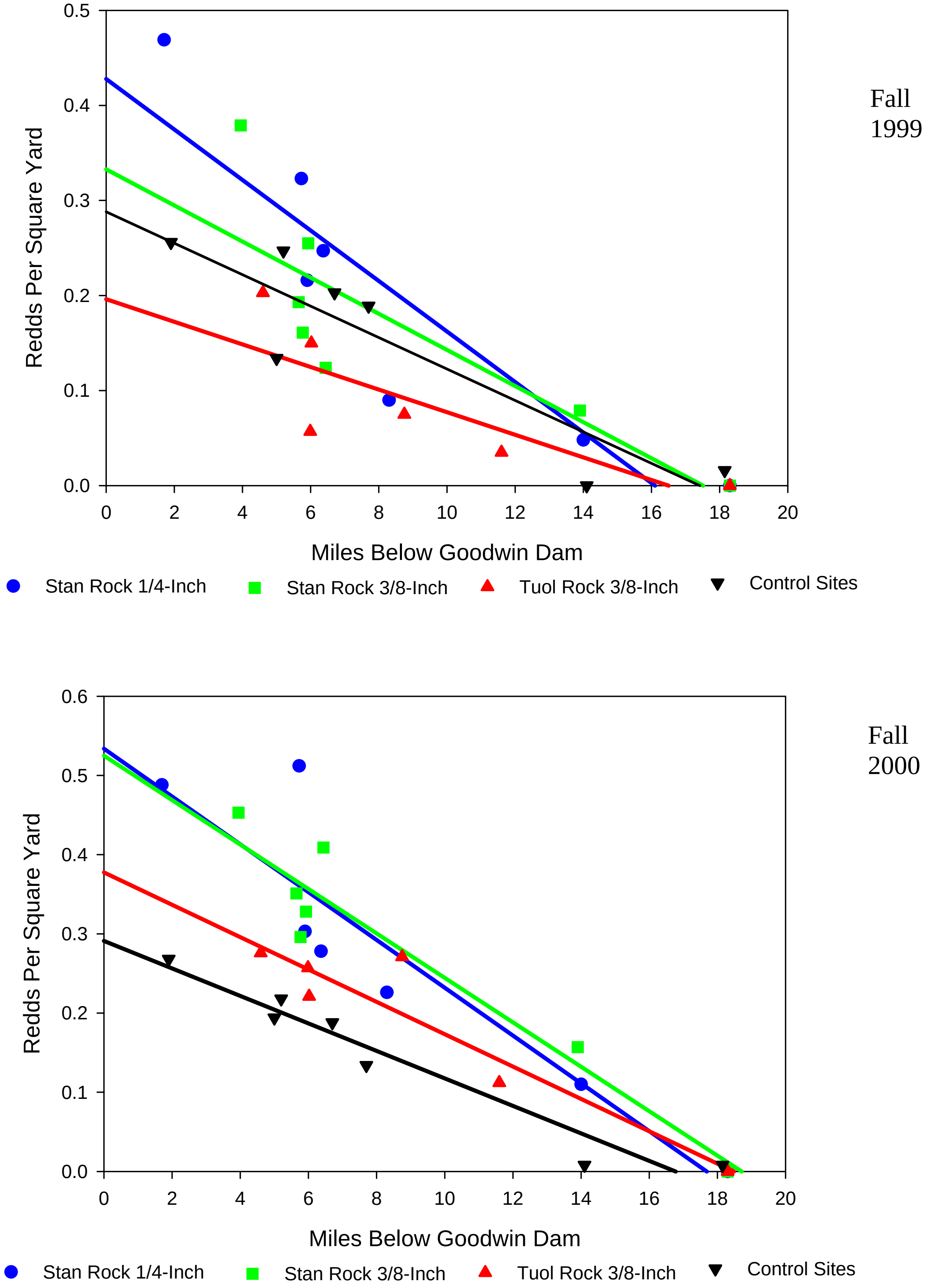

Figure 2. Chinook salmon redd densities in fall 1999 (upper figure) and fall 2000 (lower figure) at project sites that received three different mixtures of gravel: (1) Stanislaus River rock cleaned with a 1/4-inch screen, (2) Stanislaus River rock cleaned with a 3/8-inch screen, and (3) Tuolumne River rock cleaned with a 3/8-inch screen and the control sites relative to the distance below Goodwin Dam in the Stanislaus River.

cemented streambed would have loosened the gravel and facilitated subsequent redd construction. It may also have been easier for salmon to construct redds in the gravel washed with a 1/4-inch screen than in gravel washed with a 3/8-inch screen in fall 1999 (CMC 2002a) as it was noticeably easier to dig artificial redds with hoes and shovels in the gravel washed with the smaller screen. Presumably substrate particles between 1/4 and 3/8-inches acts as a "lubricant" during redd construction. If true then seasoning may also involve the intrusion of fine sediment that provides a lubricant that aids in the digging of redds.

Useful information was also provided on two methods of evaluating intragravel conditions for egg incubation. The method of driving a standpipe into the substrate to estimate permeability appears to be unreliable for two reasons. First, driving the standpipe into the substrate would greatly affect bed permeability whenever the standpipe encounters large stones that must be pushed out of the way. Second, pumping water and fines out of the standpipe to estimate permeability probably creates a channel of high permeability surrounding the standpipe that would result in an artificially high reading. These two problems would explain the poor correlations observed between side-by-side measurements of permeability and apparent velocity during this study (Figure 3) and studies conducted by Coble (1961) and Phillips and Campbell (1962). In contrast, the method of using deviations in intragravel water temperatures in artificial redds from surface water temperatures was useful because it helped demonstrate that high rates of fine sediment intrusion and upwelling of oxygen-poor groundwater primarily coincided with managed pulse flows of at least 1,100 cfs. Other factors that were associated with fine sediment intrusion in artificial redds include the intragravel transport of fines in silty riffles during normal flows and nearby redd construction. The temperature measurements also demonstrated that a majority of the problems associated with the upwelling of oxygen-poor groundwater occurred in the downstream sites where few salmon currently spawn.

One recommendation for future studies is to directly measure egg survival to emergence by planting eggs to determine the percentage of eggs that survive to hatching and also by determining emergence rates in natural redds, both at single and superimposed redds. A critical review of the literature on salmonid egg survival to emergence indicates that it is difficult to accurately estimate the percentage of salmonid eggs that survive to emergence based on habitat measurements, such as intragravel D.O. concentrations, apparent velocity, permeability, and the concentration of substrate fines (CMC 2002a). Comparisons among previous field and laboratory studies suggest that egg survival to hatching is substantially affected by the adhesion of fine sediment to the egg's membrane that inhibits the absorption of oxygen, although this presumed influence has not been quantified under field conditions. Furthermore, studies of alevin emergence rates have either used abnormally healthy alevins tested under laboratory conditions or failed to accurately estimate the initial number of viable eggs or the number of alevins that escaped from natural redds capped with netting, which makes it impossible to determine the accuracy of the egg survival to emergence estimates. Intragravel D.O. concentrations, apparent velocity, and water temperature should be monitored relative to egg survival and emergence to help develop a model that could be used to accurately predict egg survival based on habitat measurements. The turbidity of intragravel water should also be monitored to try to establish an index of the amount of fines adhering to egg membranes. Many intragravel water samples collected during the KFGRP studies were quite turbid. Permeability measurements could be made at some lots of planted eggs by installing a permanent standpipe. However, pumping substrate fines from the artificial redds during measurements may confound the results. Furthermore, there may be few benefits from permeability measurements because previous studies suggest that permeability may not be well correlated with egg survival.

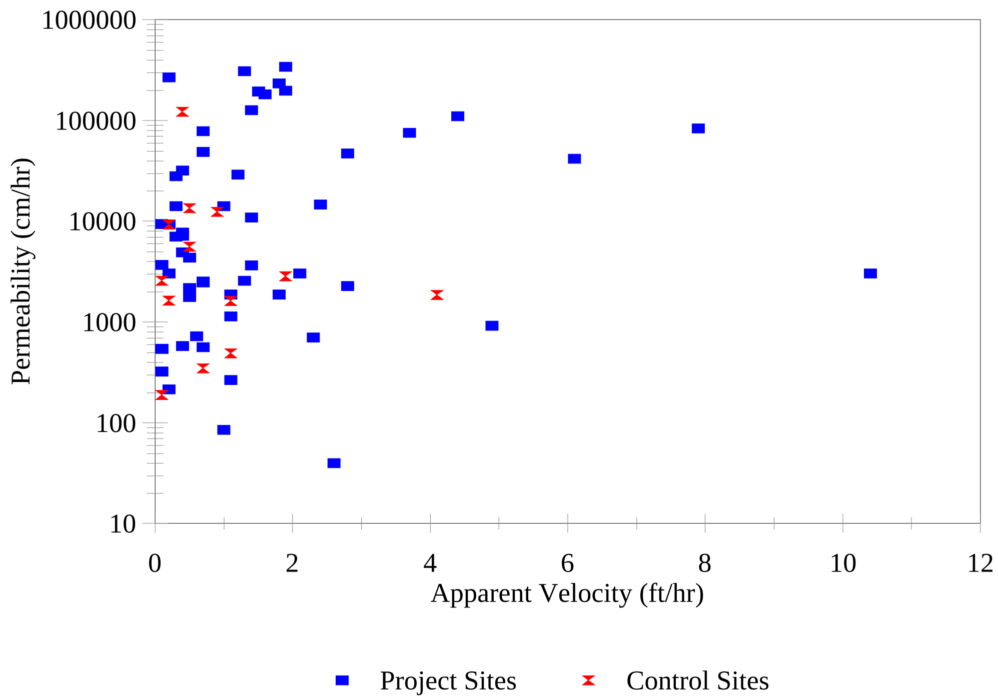

Figure 3. Scatter plot of side-by-side measurements of permeability on a common log scale versus apparent velocity in 50 artificial redds in project riffles and 17 artificial redds in control riffles in the Stanislaus River in February 2001.

Independent observations by professional fishing guides and other fishery biologists indicate that the KFGRP riffles provide excellent habitat for adult steelhead trout and juvenile chinook salmon and rainbow/steelhead trout. Mr. Steve Walser and Mr. Tim Smith, who are professional fishing guides, report that angling for steelhead trout has greatly improved at the KFGRP sites where surface turbulence and deep water provide cover and feeding habitat (Walser and Smith, personal communication). Trevor Kennedy with the Fisheries Foundation and Tom Cannon, Senior Biologist with HDR Engineering (personal communications, see "Notes"), snorkeled some of the KFGRP sites and report that numerous juvenile salmon and trout utilize the KFGRP riffles, whereas few use the nearby mined channels.

The results of the three years of habitat evaluations are summarized below.

<u>Pre-Project Habitat Evaluations</u>

The Task 3 studies produced contour maps of all study sites showing the pre-project streambed elevation in August 1999 and the location of where fall-run chinook salmon spawned in fall 1998. There were no significant differences in redd density between the control sites and the unmined portions of the project sites. Although the redd densities at the mined portions of the projects sites were substantially lower than those at the control sites, it was not possible to conduct statistical tests because the densities at the mined sites were not correlated with distance downstream.

The Task 3 studies also indicate that conditions for the survival of salmonid eggs were quite poor. The percentage of particles finer than 1 mm in 50 subsurface substrate samples averaged 11.3% and ranged from 0.23% to 35.8%. The mean permeability of 123 measurements in undisturbed gravel was 3,129 cm/hr. The mean intragravel dissolved oxygen concentration at 77 standpipe sites was 9.5 ppm and 18% of the measurements were below 8 ppm, which may be low enough to result in high rates of egg mortality. Dissolved oxygen concentrations below 11 ppm, which occurred at 70% of the standpipe sites in fall 1998, probably result in the production of small, weak alevins that were unlikely to survive (CMC 2002a). The fall 1998 measurements of intragravel dissolved oxygen were made prior to turbid storm runoff, which is typically correlated with substantial declines in dissolved oxygen (Mesick 2001b). It was not possible to collect samples after the rain storms began due to increased flows for flood control.

<u>Task 5 Initial Post-Project Habitat Evaluations</u>

The Task 5 initial post-project studies indicated that the source of gravel for restoring riffles significantly affected fall-run chinook salmon spawner use. The density of salmon redds was significantly greater ($P = 0.073$) at the sites with Stanislaus River gravel than at sites with similarly-sized Tuolumne River gravel in fall 1999. Although redd densities were about 29% higher where the gravel was cleaned with a 1/4-inch screen than at sites where the gravel was cleaned with a 3/8-inch screen, the difference was not significant ($P \geq 0.370$).

The elevation of the natural riffle's crest as measured under pre-project conditions had no measurable effect on downwelling rates in artificial redds, intragravel D.O. concentrations or the density of redds. Vertical hydraulic gradient, which is the measurement of downwelling rate used in this study, was near zero at all artificial redds in both project riffles and control riffles, regardless of the elevation of the riffle's crest. Furthermore, intragravel D.O. concentrations were near saturation at most project riffles regardless of the elevation of the riffle's crest. It was not possible to conduct a statistical analysis of the density of redds in riffles with differing crest elevations due to the low number of replicates and the confounding influences of gravel type and distance downstream. However, there were almost no differences in redd density between the high-crested, moderate-crested, and low-crested riffles near Lovers Leap that all received Stanislaus River rock washed with a 3/8-inch screen. The results also suggest that chinook salmon are equally likely to spawn at restoration riffles created by adding gravel to extensively mined channels, naturally flat channels, or the natural tails of pools.

The intragravel D.O. concentration at the project sites was significantly greater than the concentrations measured at the control sites in mid-December 1999, which is about the time when the eggs began to hatch, and in early February 2000, which is when most eggs had hatched. The mean D.O. concentration was 10.7 ppm at 68 artificial redds in the restoration sites and 9.3 ppm at 27 artificial redds in the control sites in mid-December. The mean D.O. concentration was 11.1 ppm at 31 artificial redds in the restoration sites and 9.7 ppm at 16 artificial redds in the control sites in early February 2000. The D.O. concentrations measured at 98.5% of the artificial redds in project riffles were probably sufficient to maximize the survival of chinook salmon eggs to hatching ($\geq$ 8.0 ppm), whereas the D.O. concentrations measured in the control riffles would have produced high rates of survival at only 77.8% to 84.6% of the artificial redds. Furthermore, the high D.O. concentrations at the project riffles would have produced larger and healthier alevins that would be better able to emerge and compete for food after emergence than the fry produced at the control riffles.

Streambed permeability in the undisturbed beds of the riffles, which was used as a measure of intragravel flow for this study, was significantly greater at the project riffles where the restoration gravel was at least 12 inches deep than at the control sites throughout the fall 1999 incubation period. Furthermore, the permeability of the riffle bed was sufficient to nearly maximize ($\geq$ 80%) the expected survival of chinook salmon eggs to emergence based on laboratory studies at two-thirds of the locations sampled in the project sites in early February after several turbid rain storms. After most of the eggs had incubated and the flood control releases began in mid February 2000, permeabilities increased at most project riffles but declined significantly at the upstream half of many project riffles in the Lovers Leap reach (riffles R13-R20) to levels that were similar to those at the control sites. It is likely that fine sediment was deposited at high rates at the riffles near Lovers Leap because this is an area of relatively recent and extensive gravel and gold mining.

Monitoring intragravel water temperatures in artificial redds and surface water temperatures provided data that were useful for detecting the timing and relative magnitude of fine sediment intrusion and the upwelling of oxygen-poor groundwater. Intragravel water temperatures rapidly changed after installing the thermographs in mid October 1999 from closely matching surface water temperatures in magnitude and fluctuation to becoming elevated by 0.8 to 13 degrees Fahrenheit and relatively stable at six artificial redds. As an example of this pattern, the intragravel and surface water temperatures at artificial redd P4 at control riffle R10 are shown in Figure 4. The intragravel dissolved concentration was usually below 8.0 ppm at these six sites. The changes at these artificial redds were not related to changes in flow, storm runoff, or nearby redd construction. The site features suggest that the elevated and stabilized water temperatures resulted from fine sediment intrusion that decreased the ratio of surface flow downwelling to groundwater upwelling. Furthermore, the fine sediment intrusion probably resulted from the intragravel transport of fines within silty riffles during normal flow releases.

Intragravel water temperatures also became stabilized and slightly elevated at 44% of the artificial redds usually beginning on 15 February 2000, which was one day after 1,500 cfs flood control releases began. About half of these sites occurred near Lovers Leap, where bed permeabilities significantly declined after the flood control releases. As an example of this pattern, the intragravel and surface water temperatures at artificial redd P4 at project riffle R19 are shown in Figure 5. In late June and early July 2000, the mean intragravel D.O. concentration at these sites, which was 7.7 ppm, was significantly lower than the mean intragravel D.O. concentration of 9.3 ppm which occurred at the sites where no temperature deviations occurred.

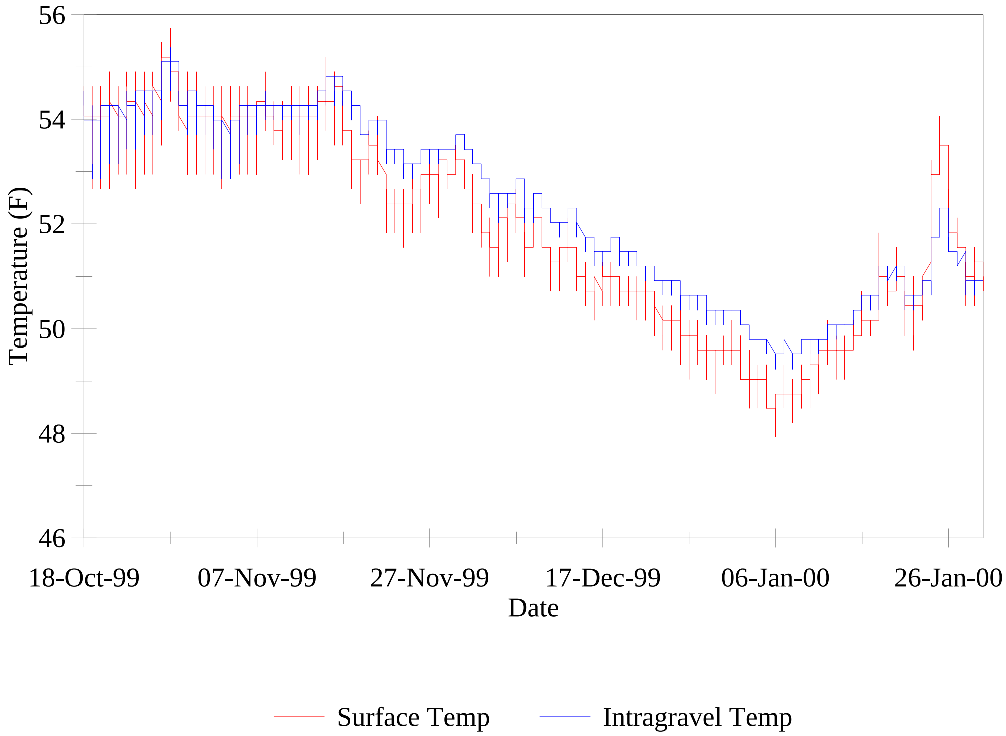

Figure 4. The surface and intragravel water temperature at artificial redd P4 in Riffle R10 in the lower Stanislaus River from 22 October 1999 to 30 January 2000.

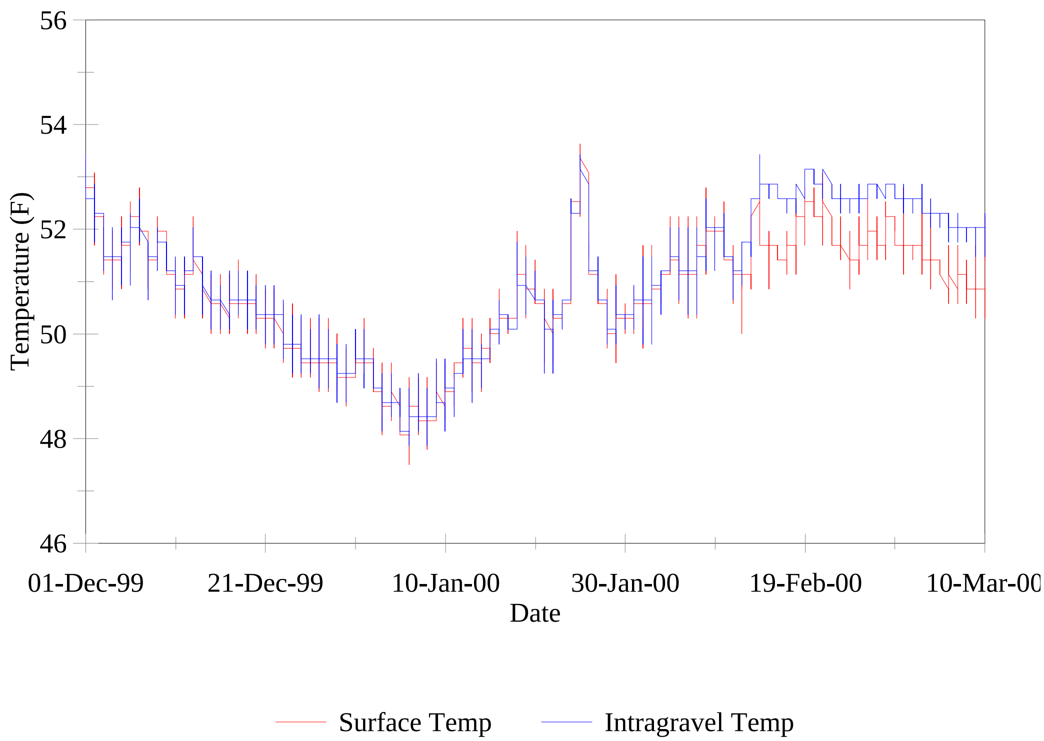

Figure 5. The surface and intragravel water temperature at artificial redd P4 in Riffle R19 in the lower Stanislaus River from 1 December 1999 to 10 March 2000.

Task 6 Second Year Post-Project Habitat Evaluations

The density of redds was significantly greater at project riffles with Stanislaus River rock cleaned with a 3/8-inch screen and at the sites with Tuolumne River rock than at the control riffles in fall 2000. Although the redd densities at the project riffles with Stanislaus River rock cleaned with a 1/4-inch screen were similar to those at the project riffles with Stanislaus River rock cleaned with a 3/8-inch screen and substantially higher than those at the control riffles, it was not possible to verify these differences with statistical tests. Compared to fall 1999, redd densities increased at the project sites, particularly those with Stanislaus River rock cleaned with a 3/8-inch screen and Tuolumne River rock (Figure 2). This increase in relative spawner use at the restoration sites suggests that the restoration rock had “seasoned” during the first 12 months after placement in the river such that the gravel became more attractive to spawning salmon.

Redd densities at restoration sites with Stanislaus River rock washed with a 3/8-inch screen were about 41% higher than the redd densities at nearby restoration sites where similarly sized Tuolumne River rock was added. The difference was significant ($P = 0.018$) based on a *F*-test that compared the elevations (intercepts) of the regressions of redd density versus distance downstream.

The elevation of the natural riffle’s crest as measured under pre-project conditions was not correlated with downwelling rates or the apparent velocity in artificial redds, or the density of chinook salmon redds in the restoration gravel. Vertical hydraulic gradient, which is the measurement of downwelling rate used in this study, was near zero at all artificial redds in both project riffles and control riffles, regardless of the elevation of the riffle’s crest. Both the fall 1999 and the fall 2000 results suggest that chinook salmon do not differentiate between restoration sites where gravel has been added to extensively mined channels, naturally flat channels, or the preferred natural sites at the tails of pools.

Chinook salmon are able to create suitable egg incubation conditions by cleaning the fines from the substrate during redd construction in both restoration and natural riffles as indicated by the permeability measurements made in chinook salmon redds. However, subsequent redd superimposition is common in the Stanislaus River and probably results in high rates of egg and alevin mortality. Ten to 200 entombed alevins were observed at 31.6% (six) of nineteen superimposed redds that were partially excavated to retrieve the piezometers in early February 2001. At one superimposed redd, approximately half of the entombed alevins were still alive but in a highly emaciated condition. Since only the margins of these redds were excavated, it is likely that the true number of superimposed redds with entombed alevins and the number of entombed alevins in each redd were probably much higher than reported above. In contrast, entombed alevins were not observed at any of the five non-superimposed redds that were fully excavated at riffle R19A, a project site, and at only two of seven non-superimposed redds that were fully excavated at riffle R20, a control site. Combining the results from riffles R19A and R20, only 16.7% (2 of 12) of the non-superimposed redds contained entombed alevins. Furthermore, the number of entombed alevins was relatively low at the non-superimposed redds at riffle R20: Only one dead alevin was observed at one redd and approximately 50 dead and 10 highly emaciated alevins were observed at the other.

Redd superimposition occurred at 71% of the artificial redd sites during fall 2000. Redd construction by chinook salmon resulted in the complete excavation of 24% of the artificial redds, which would have killed most of the eggs in an actual redd. In addition, salmon superimposed their redds on top of another 23% of the artificial redds, which would have entombed some or all of the alevins in an actual redd. Twenty-four percent of the artificial redds had some of the gravel scoured away by salmon that used the artificial redd's gravel to construct a redd slightly downstream of the artificial redd. The scouring away of gravel by superimposing female salmon frequently increased intragravel flow in the egg pocket of the artificial redds and probably harmed few eggs. Further study is needed to quantify mortality due to entombment.

Unlike the fall 1999 studies, intragravel D.O. concentrations in artificial redds were not significantly different between the project and control sites in December 2000, when the eggs begin to hatch, or in early February 2001, after most of the eggs have hatched. The D.O. concentrations were usually greater than 8.0 ppm at almost every artificial redd, which is probably adequate for high egg survival rates. The relatively high D.O. concentrations observed during the fall 2000 study period were probably a consequence of the below average amount of turbid storm runoff.

Although measurements of intragravel flow rates were significantly higher in project sites than in control sites, the flow rates were probably high enough in both project and control sites for high rates of egg survival. Apparent velocity measurements taken prior to the late October 2000 pulse flow suggest that intragravel flow rates in redds constructed after the pulse flow would average about 6 feet/hour in both the project and control sites, whereas egg survival is usually high at flows greater than 1.5 feet/hour (Gangmark and Bakkala 1960, Coble 1961, Phillips and Campbell 1962). Upwelling of oxygen-poor groundwater, as indicated by deviations in intragravel water temperatures from surface temperatures, primarily occurred in the downstream sites where few salmon spawn. The relatively good incubation conditions observed at all sites in fall 2000 probably resulted from a dry winter and a lack of turbid storm runoff through January 2001. High rates of turbid storm runoff during previous studies substantially reduced intragravel D.O. concentrations in redds in the Stanislaus River and probably coated incubating salmon eggs with a suffocating layer of silt. Further study is needed to evaluate the effect of turbid storm runoff on incubation conditions during normal and wet years.

A bed mobility analysis for some of the KFGRP project riffles suggests that flows of 5,000 to 8,000 cfs are necessary to mobilize the median diameter of the channel bed material (Kondolf et al. 2001). During spring 2000, flow releases from Goodwin Dam ranged between 3,000 and 3,500 cfs for about 10 days. As a result, gravel movement primarily occurred at only four of the 18 project riffles where large instream structures, such as large boulders, bridge pillars, large trees, and highly vegetated mid channel gravel bars, caused localized areas of scour. Further fluvial geomorphic evaluations are needed after flows have exceeded 5,000 cfs.

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